Topographical Equilibrium of Coastal Inlets(海岸水路における地形平衡)

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論文内容要旨

A coastal inlet is the waterway connecting a sea with a lagoon or river and generic name of river mouths and tidal inlets. Davies (1964) previously classified the environment affecting the inlets topography, in terms of tides, into micro, meso, and macro tidal ranges. However, as indicated by Davis and Hayes (1984), not only tides, but also waves or river flows, or these combinations affect the topography. Wave influence is especially important in sandy coasts, which can be seen in the topographies of sand spits and barrier islands which narrow river mouths and tidal inlets respectively.

Longshore currents induced by waves transport littoral sediment and develop such topographies by depositing them, where river flows and/or tidal currents have an opposite function of removing the deposited sediments. In some cases, inlets are completely closed when river flows or tidal currents become weak because they cannot remove the deposited sediment at the inlets. These inlets usually have narrow width of less than 100 m even for the fully open state. They exist in micro-tidal, wave-dominated coastal environments where strong seasonal change of river flow and wave climate is experienced. Some of them are extensively used for navigation channels connecting the sea and harbors for small boats. Hence, the seasonal narrowing or closure of the inlets causes navigation problems because it restricts the access to the sea. The closure also causes inundation for the surrounding area of the inlets in the following rainy season, because the flood flow often spills before it flushes out the closed part. To have year-round navigability and to improve the flushing capacity of coastal inlets, the ways of keeping the inlets permanently open have been an increased interest. Therefore, it is obvious that sustaining engineering solutions for these problems need a proper understanding of dynamic equilibrium condition of coastal inlet topography and knowledge of the dominant processes causing the inlet closure. An alternative approach would be to develop a model, which could be used to understand influences of the external forces. Furthermore a model can help in understanding the dominant processes governing the closure. The application of such a model is cost-effective and is also useful in determining the consequences of any proposed engineering solutions.

Most existing coastal inlet models assume only a couple of factors, e.g. river flows and waves or tides and waves. These assumptions are applicable only for tidal inlets or river mouths where the tidal effect is negligible. This study includes the three factors to deal with and aims the unification of the two phenomena's knowledge by presenting universal relationships. Furthermore, the study considers a coastal inlet on a sandy beach with neither geologic nor vegetational controls such as a rock, clay substratum or mangrove. Riverine sediment transport is also disregarded because this study considers calm condition on river flows. Only littoral/longshore transport is assumed to cause sedimentation and inlet current by river flows or tides to cause erosion. In addition, an unbalanced wide inlet is assumed as an initial condition. While continuous sediment supply from littoral drift bears sedimentation and narrows the inlet, increase of the velocity and then the traction force by decrease of cross section increase the sediment removal rate at the inlet. Thus we can expect the balance of the sediment supply and removal rates in the narrowing process. We define this balance as equilibrium in sediment transport or simply as equilibrium. Based on this definition, an evaluation on topographical equilibrium of coastal inlets has been done in this study.

Then, a volumetric sediment transport equation propounded by Aota and Shuto (1980) is used to develop a topographical model of coastal inlet. The equation has been extended by inclusion of tides. This inclusion is advanced the model which is applicable for evaluation on river mouth topography as well as geometry of tidal inlet. To generalize the equation, a dimensionless expression is derived. Two dimensionless parameters ϕ_R and ϕ_T, which are ratios of volumetric sediment remove by river flows and by tidal currents to volumetric sediment deposition by littoral drift respectively, are introduced. A new dimensionless parameter γ, which represents the ratio between volumetric sediment transports by tidal currents and by river flows, is also introduced in the derivation of dimensionless form. Finally, a set of dimensionless equations subjected to the change of inlet width under the three actions of river flows, tides and waves is resulted. The three actions are now degenerated into the two dimensionless parameters ϕ_R and γ or ϕ_R and ϕ_T.

Regarding to sediment remove conditions, i.e constant river flows and no tides, tides with constant amplitude and no river flows, river flows and tides, the equilibrium is examined. An analytical solution is obtained when the first condition is considered. This solution is applicable to evaluate the equilibrium at river mouths where tides are negligible.

Similar solution is also resulted from the model equation if the second condition is applied. The solution is capable of predicting of tidal inlet geometry. For the third condition, the equation cannot solve analytically then it solved numerically by fourth order Runge-Kutta method. In order to examine the second and the third solutions, data of the Abukuma River in Japan and several rivers in Indonesia are used. The Abukuma River mouth have been observed frequently and variously, and thus have a large amount of data on the river flows, tides, waves, littoral drift, topographies, and bed materials. The littoral drift was evaluated by sediment accretion at the weather side of jetties constructed near the river mouth as 3.2x104 m^3/year. In particular, sand spit development in front of the mouth has been also evaluated using aerial photographs and validated by means of oftentimes measurements in the previous study (Mano et al., 1995). By comparing the littoral drift and the volumetric expansion rate of the sand spit, the efficiency factor used in the examination was also estimated as $e_w = 0.67$. It is also reported from the analysis of the spit development that it commonly elongates and narrows the mouth width after flood passage. Then, the narrowing ceased after 4 –12 months and the width remains stationary at 50 – 60 m. Especially at winter season when wave condition in front of the mouth is slightly steady and river discharge is almost constant, the mouth also has stationary width within the range of those values. Comparison between data and calculation shows that The Abukuma river data is close to the theoretical solution.

On the other hand, Indonesian rivers have fewer data especially on the topographies and waves. We obtained data of river discharge, sediment materials and topographies of the Serayu, Opak, Tipar, and Bogowonto Rivers from the Indonesian-RIWRD, Research Institute of Water Resources and Development. As shown in Fig.4, these rivers in the southern part of Java island flow to the Indian Ocean. During dry season, May to September, sand spits at the river mouths develop because of high waves and decrease of river discharge. Topography data obtained as occasional cross sectional surveys and aerial photographs. Only the topographical data obtained in dry season or in the transient are adopted.

Since there is neither observation on littoral drift nor on waves along the coast, we estimated the drift based on five year re-analysis waves data from ECMWF, European Centre for Medium-range Weather Forecasts. by assuming topographies equilibrium, we compared the Indonesian rivers data with theory. The assumption is also examined later. The comparison shows that the solutions agreed with data and they are capable to indicate the equilibrium state of those rivers. Additionally, the second analytic solution recovers the forms of the well-known empirical formula $A_c = C\,(P_T)^n$, where A_c is the equilibrium cross-sectional area, P_T is the tidal prism, and C and n are constants. An explicit expression in obtained for C in terms of coastal sediment transport processes. To examine validity of the obtained formulation, we evaluated C for the inlets along the Atlantic, Pacific and Gulf coasts. The representative values of parameters used in the evaluation were obtained from the Unites State Army-Coastal Inlet Research Program website. Evaluation results are in the range found empirically and it can explain that C is not constant but the magnitude depends on the coastal sediment transport processes. Although the exponent obtained from analytical derivation is considered greater than the empirical one, comparisons between the model derived from analytical solution and data of inlets along the Pacific, Atlantic and Gulf coast in USA have close correlation. It infers that the model is capable of predicting the cross-sectional area of tidal inlets without necessity of determining an empirical coefficient. In addition the coefficient can be estimated from parameters relating to coastal sediment-transport processes. In summary, the model in this study also contributes to explain the relationship between equilibrium cross-sectional area in tidal inlets and it's tidal prism based on the knowledge of coastal sediment transport processes.

In time-dependent mode, the third solution of the model in this study is used to reproduces the time span to reach equilibrium at the Abukuma River mouth. Calculation to reproduce this time scale gave a reasonable value and it is in the range of the measured one. The solution in this mode is also used to examine the equilibrium assumption. The examination is directed to evaluate the time span of topographical response. The time spans obtained from calculation are ranging from 1 to 3 days and from 3 hours to 2 days for the Serayu and Opak River mouths respectively. These time spans are very short and they are representing that the topography give a quick response. Furthermore, the short time spans implies that the width of river mouths is also rapidly adjusted to the actual conditions of the external forces. In this condition the assumption of equilibrium topography is valid. As a final topic, we examined the effect of jetty on the equilibrium topography. By means of five sediment transport formula, we calculated distribution of longshore transport in across shore direction. Based on these calculations, a formula to calculate sediment-blocking coefficient caused by jetties is proposed. Then, the formula is applied to examine the effect of jetty on the tidal inlets topography. Finally, three recommendation are proposed to continue this study in the future as listed below:

- The equilibrium was simply defined as balance of sediment in this study deposition from littoral drift and sediment remove by inlet currents. It is regardless the existence of sediment input from river and cross-shore sediment transport. In some cases, these sediment processes can be significant. Therefore it is necessary to consider them in the new definition of equilibrium while their influences become dominant.
- The model in this study is 1D model which considered simple interaction between river flows and tidal currents. It is also regardless interactions between longshore currents, tidal currents and river flows in front of the inlets whereas these interactions can bear complex hydrodynamic condition which significantly affects the sediment transport processes in the inlets. To consider this condition, it is necessary to improve the model into 2D or even 3D model
- Because of the complexity of topographical change and sediment processes at coastal inlets, we need to investigate them step-by-step as a part of an integrated research. This study was also conducted to contribute in understanding those phenomena and it is expected to a part of the integrated research.

References:

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論文審査結果の要旨

海岸水路と総称される、砂浜海岸に開口部をもつ河口や潟湖入口には、波浪、河川流、潮汐の３つの外力が作用する。ここでは、波浪が運ぶ沿岸漂砂の堆積作用と、水路を通る河川流や潮汐流の侵食作用により開口部の地形は変化し、２つの作用が釣り合ったときに地形は安定する。河川流量の減少や、潟湖埋め立てに伴う潮汐流の減少は、開口部における砂州の発達を促し、洪水の疎通阻害や航行障害を引き起こすため、これら外力と開口部地形の関係を見つけることは工学上の重要課題であった。

本研究は、これら３つの外力が作用するときの地形平衡を表す普遍関数を解析的に導き、この解が各国の観測データとの比較により良い精度と広範な適用性をもつことを証明したものである。

第１章は序論であり、研究の背景、必要性、目的を述べている。

第２章は文献調査であり、既往の研究を調べ、河口の問題と潟湖入口の問題が個別に扱われ、経験的な関係の導出に力点がおかれていたことを総括した。

第３章では土砂収支解析を行った。波浪、河川流、潮汐が運ぶ土砂と開口部砂州の発達の関係を表す微分方程式を導き、無次元化することにより、3つの外力の作用の相対的な関係を表す２つの無次元量ϕ_Tとϕ_Rを導いた。これは、問題を簡単化したものであり重要な貢献である。

第４章では、前章の特別な場合として堆積と侵食が釣り合う平衡状態について解き、開口幅を、２つの無次元量で表す関数を得た。さらに、この結果を日本とインドネシアの河口に適用し解の妥当性を検証した。これは、解の普遍性、有用性が高いことを示したものである。

第５章では、さらに特別な場合として潟湖入口の平衡条件への応用を行った。従来、観測値の回帰によって得られ、広く用いられてきた経験式と似た関係が、解析解の特別な場合として導かれること、経験式は限られた条件で成り立つことを明らかにした。これは、従来の知見を統合したものであり、学術的に重要な貢献である。

第６章では、開口部に堆積する沿岸漂砂を制御するために従来広く用いられてきた導流堤の効果について定量化した。これは導流堤の設計や評価に用いることが出来、工学的に有用な知見である。

第７章は結論である。

以上本研究は、２つの有用な無次元量を導き、従来の河口、潟湖の地形平衡に関する知見を統合する新たな普遍関数を提案し、河川工学や海岸工学の発展に寄与したものである。

よって、本論文は博士（工学）の学位論文として合格と認める。